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GENERATION OF A REPRESENTATIVE LOAD SEQUENCE FOR THE FATIGUE TEST--ETC(U)

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ARL-STRUC NOTE-450

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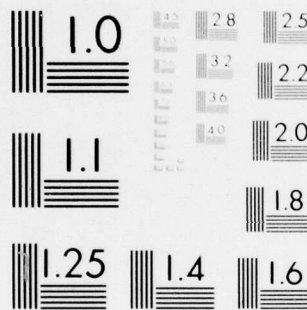
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MELBOURNE, VICTORIA

STRUCTURES NOTE 450

**GENERATION OF A
REPRESENTATIVE LOAD SEQUENCE FOR THE
FATIGUE TESTING OF MACCHI MB 326H SPAR BOOMS**

by

L. R. GRATZER

Approved for Public Release.



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9 STRUCTURES NOTE 450

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**GENERATION OF A
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10 L. R. GRATZER

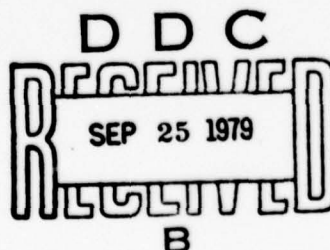
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SUMMARY

This Note describes the development of a flight load sequence for the fatigue testing of Macchi MB 326H spar booms. The procedure involves the use of linear programming and may be applied to other structures.



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1. INTRODUCTION

As part of the fatigue life assessment of the R.A.A.F. Macchi MB326H aircraft, a full scale fatigue test was carried out by the manufacturer, Aeronautica Macchi, S.P.A., Varese (Ref. 1).

Since then, testing techniques have been developed to allow more realistic load sequences. To take advantage of this, the design of such test sequences must also be improved and for several years large scale tests at ARL have relied on loads obtained from flight histories transformed as little as possible. In this way the probability structure of flight sequences can be restored.

Until now however, the design of test histories has been almost entirely manual. This note describes the generation of histories by use of automatic data processing techniques and linear programming.

The example used in this note is the Macchi centre section spar boom which is being tested under the design load history to supplement earlier data obtained under less realistic load sequences (Ref. 2).

2. DATA

2.1 Fatigue Meter Spectrum

The FM spectrum for this analysis was obtained from magnetic tape *1 containing R.A.A.F. FM data. The data was from flights at No. 2 Flying Training School (2BFTS) Pearce, during 1973, 1974 and 1975, on aircraft fitted with 70 gallon fuel tanks and no stores.

It comprised 15,748 flights made up of 9 types of flying (TOF). Of these, 2 were flown so infrequently (9 times) that they could be safely ignored. The remaining 7 were analysed (Table 1) and then scaled to 200 flights (Table 2).

2.2 Flight Loads

Loads were obtained from histories of flight trials conducted in 1974 at Laverton and Williamstown (Ref. 3, Table 3).

The test aircraft was Macchi A7-005. Forty-nine channels of analogue data were each sampled 60 times per second by a multiplexer, converted to digital form, and written onto magnetic tape on a recorder mounted in the rear cockpit.

The following variables were recorded: normal, lateral and longitudinal acceleration; roll, pitch, and yaw rates; rudder, aileron, and elevator position; airspeed; altitude; sideslip; incidence and rudder force. The remaining channels were connected to electrical resistance strain gauges on the fin and the centre section main spar.

3. METHOD

3.1 Sequence of Flights

The method followed for producing the flight sequence was that employed by Howard (Ref. 4).

Two event frequency tables were produced by analysis of the Pearce flight data. The first (Table 4) shows the frequency with which the subject mission is followed by a different mission (transition frequency). The second (Table 5) shows the frequency of occurrence of various run lengths (number of times the mission is flown before a different mission occurs).

The ordering observed is similar to that found for the Mirage III by Howard. It will be

*1 provided by AIRENG5A1, DEFAIR.

noted that the row sums in Table 4 must sometimes differ from the corresponding column sums. This follows from the fact that only transitions to *unlike* missions are included and that row sums are *following* missions whilst column sums count missions *before* a given type. Further analysis indicates that, save for inevitable miscounting, corresponding row and column sums are mostly equal. The two exceptions are the counts for first and last flight types which may differ by one.

The FM data analysed related to 15,748 flights, and had to be scaled to 200 flights for the test. This was accomplished by multiplying all values in the frequency tables by 200/15,748. Fractional values in the transition frequency matrix were eliminated by rounding off to the nearest integer. The run length table required slightly more complicated treatment. Flights representing fractional frequencies of run length were accumulated until an integral number of shorter runs could be formed. For example a frequency of 0.5 for a run length of 12 and 0.55 for a run length of 11 became one run of 11 with one flight carried to shorter run lengths.

On rounding off the transition frequency matrix, a number of flights were lost and had to be restored. The method used is shown in Appendix 1. The resultant matrix is shown on Tables 6 and 7. In Table 6 the scaling and rounding has also removed the differences between row and column sums. This situation, which is physically impossible, leads to the end effect described below.

The actual flight sequence was created using the matrices in Tables 6 and 7. This was done in the following way:

A TOF is selected, in this case the least severe, TOF 0 (to ensure that the sequence does not commence with a high load application). A subsequent TOF is then selected at random from the transition frequency table, the next step is to look at the run length table and choose a run length at random of this subsequent TOF. Then back to the sequence table to choose the next following TOF and so on, each time subtracting one from the appropriate position in each table. This is repeated until the tables contain all zeros.

Inherent in this method, however, is an end effect. This adds an extra flight into the matrix at the start. Before the tables are completely exhausted we find ourselves in a row containing all zeros and therefore unable to select the next TOF or proceed. To overcome this difficulty we backstep to the last transition and subtract one from the matrix at the point that led into the all zero line. Then go back to the beginning and start again. Though apparently fairly tedious, use of the digital computer greatly facilitates the effort.

3.2 Compression of Flight Trials Data

As fatigue testing only requires turning points, all other data can be filtered out. The compression of the flight trials data was accomplished in two stages. The first stage was to extract data that may be used in a later fatigue analysis of the structure, and the second extraction extracts from these data only what is required to provide load sequence in the spar boom for the fatigue test.

STAGE 1

Fifteen channels were selected for data extraction (Table 8). These channels have been found to be the most important from previous analyses (Ref. 5 and 6). Before a turning point can be extracted, discriminators need to be chosen in order to eliminate negligible load changes (effectively the smallest range pairs). The discriminator is the required difference that must be exceeded before a turning point is registered. For example (see Fig. 1) if d = discriminator and among the four turning points:

$$e > f < g > h$$

and

$$f > h \text{ and } g < e$$

then if $g - f < d$, g and f will be excluded from the data.

The discriminators chosen were:

For normal acceleration (n_z):	0.25 g
For strain gauges on centre section: (strain is linearly related to n_z)	strain corresponding to 0.25 g
For strain gauges in the fin:	an arbitrary value of 50 microstrain

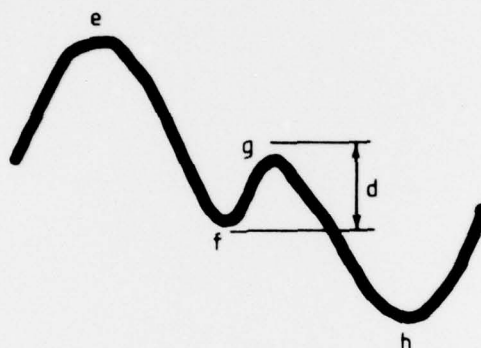


FIG. 1. USE OF DISCRIMINATOR

The fifteen channels selected were scanned by a computer program (MACEXT.F4), and when a turning point occurred on any one of the fifteen channels then the data from all 49 channels were converted to engineering units (Ref. 7), scaled and written onto magnetic tape. The compressed data occupy three tapes entitled "Macchi MB 326H Flight Trials Stage 3 — Edited Data , Engineering Units" tapes 1, 2, 3.

STAGE 2

From each of the Edited flight tapes, the Normal Acceleration— n_z was extracted and passed through a turning point routine (TURNPT.F4) to produce nine files containing turning points of n_z each representing a different history. Due to the small number of histories available, a number of quasi-flights was generated by scaling every turning point on the nine flights by the relation:

$$n_q = K(n_z - 1) + 1 \quad (\text{Ref. 4})$$

where n_q is the scaled Load Factor, n_z is the original Load Factor and K has the value 0.8 to 1.4 incremented by 0.1.

The values of K selected have been used previously (Ref. 4) and were found to be suitable in this project. The scaling produces the same type of flying but with allowances for different pilots flying the same mission.

This produced 7 flights for each of the 9 flight histories, giving a total of 63 flights (Fig. 2).

A Macchi MB 326H fatigue meter type count was done on the 63 flights to produce an FM spectrum for each (Table 9).

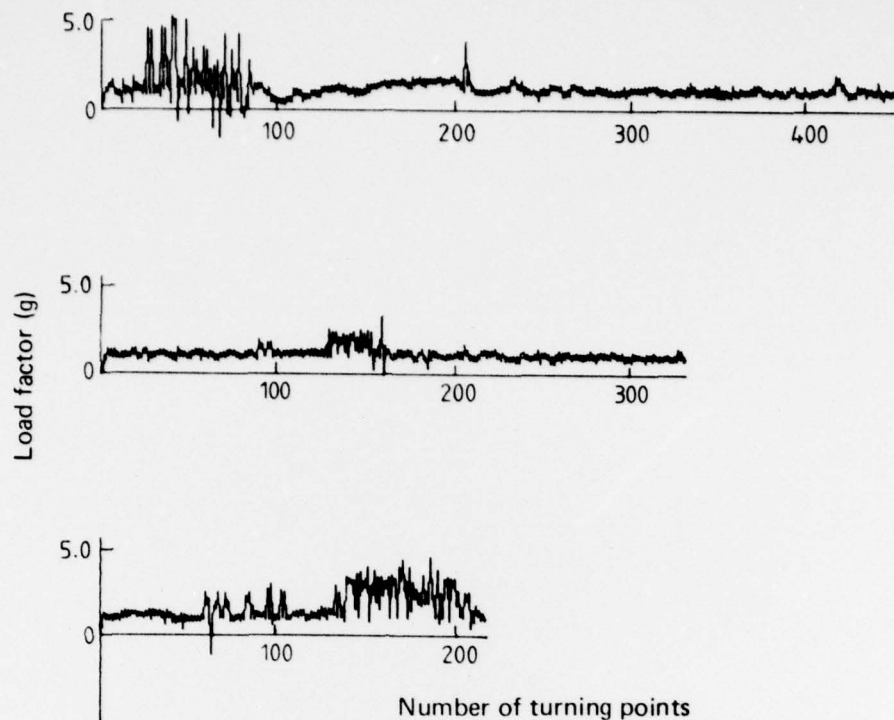


FIG. 2. THREE TYPICAL FLIGHTS

3.3 Creation of a Test Flight Sequence Tape

Analysis of the fatigue meter data produced a series of 200 flight numbers in which 7 TOF's occurred in a sequence typical of squadron usage. Nine flight trials flights were processed as above into 63 histories. To create the test flight sequence tape, a flight history had to be matched to each of the 200 flight numbers. This would be a simple matter if each of the flight histories represented a TOF classification. This is not the case (Ref. 6) and so the TOF's and the 9 flight trials flights were grouped.

The grouping involved placing of histories and TOF's of similar flight descriptions into separate groups. On performing the linear programming to match the histories with TOF's, no feasible solution was possible until the number of groups was reduced to 2 (Table 10).

An FM spectrum was drawn for the 2 types of flying (Table 11). It was then required to find out what combination of the flight trials (including the quasi-flights) will produce the same FM spectrum and at the same time maintain the number of each type, as shown in table 11. This was achieved by linear programming for each type. (See Appendix 2 for worked example.) Flight 1381 was unable to be matched up and was slightly altered to achieve a match. The new flight is coded 138B. The results are shown on Table 12. As can be seen from Tables 11 and 12 a good match has been achieved. By using the information from Table 10 with the results shown in Table 12, a computer program (MASEQ.F4) moves down the flight sequence list (Sec. 3.1) and, flight by flight, (using flight trials histories) writes onto magnetic tape the appropriate history.

It is at this point that corrections are carried out (i.e. inserting one 6 g level, subtracting two -1.5 g, adding one -0.5 g and subtracting one 2.5 g levels). A fatigue meter type count was then done on the complete tape of the 200 flights the results of which appear on Table 13 together with the totals from Table 11.

The final product is a magnetic tape containing 200 files, entitled "Macchi fatigue test—200 flights—Turning Points". Each file represents one flight. The FM spectrum of this tape matches that required from the Pearce FM data (Table 13, Fig. 3).

To achieve representative loading, each n_z value on the test tape must be converted to load units. The effective critical stress sensitivity for the weakest section boom currently flying (04a) is 92.5 MPa/ n_z (Ref. 8). The end load on the test specimen (an 04 of smaller area) is determined by increasing the stress in the ratio of boom areas, back calculating the expected strain at the monitored strain gauge and then by experiment calculating the end load against gauge response. In symbols, test load

$$L_{04} = L_{04A} \frac{A_{04}}{A_{04A}} \cdot \frac{\sigma_{\text{critical}}}{\sigma_{\text{gauge}}} \cdot \frac{\epsilon_{\text{experimental at gauge}}}{\epsilon_{\text{predicted at gauge}}}$$

where A , σ , ϵ are boom areas, calculated stress and strain respectively.

The value arrived at is:

$$\text{Load} = 24.88 n_z \text{ Kips}$$

or in SI units

$$\text{Load} = 110.67 n_z \text{ KN}$$

4. DISCUSSION

A simulated sequence of 200 flights representing a scaled sequence of actual flying encountered under squadron usage has been produced. This will be used in the centre section spar fatigue test.

This sequence is only one of many possible combinations. Other sequences could be generated by changing the starting point and/or using different random data.

The technique employed requires very little judgement by the operator and appears to be widely applicable. The main drawback is that it relies heavily on the existence of an adequate set of representative flight loads and fatigue meter data, which are not always available.

A list of computer programs used and their functions can be found in Appendix 3.

5. ACKNOWLEDGMENTS

The author wishes to express his appreciation to B. E. Anderson and P. J. Howard for their assistance in the preparation of this note.

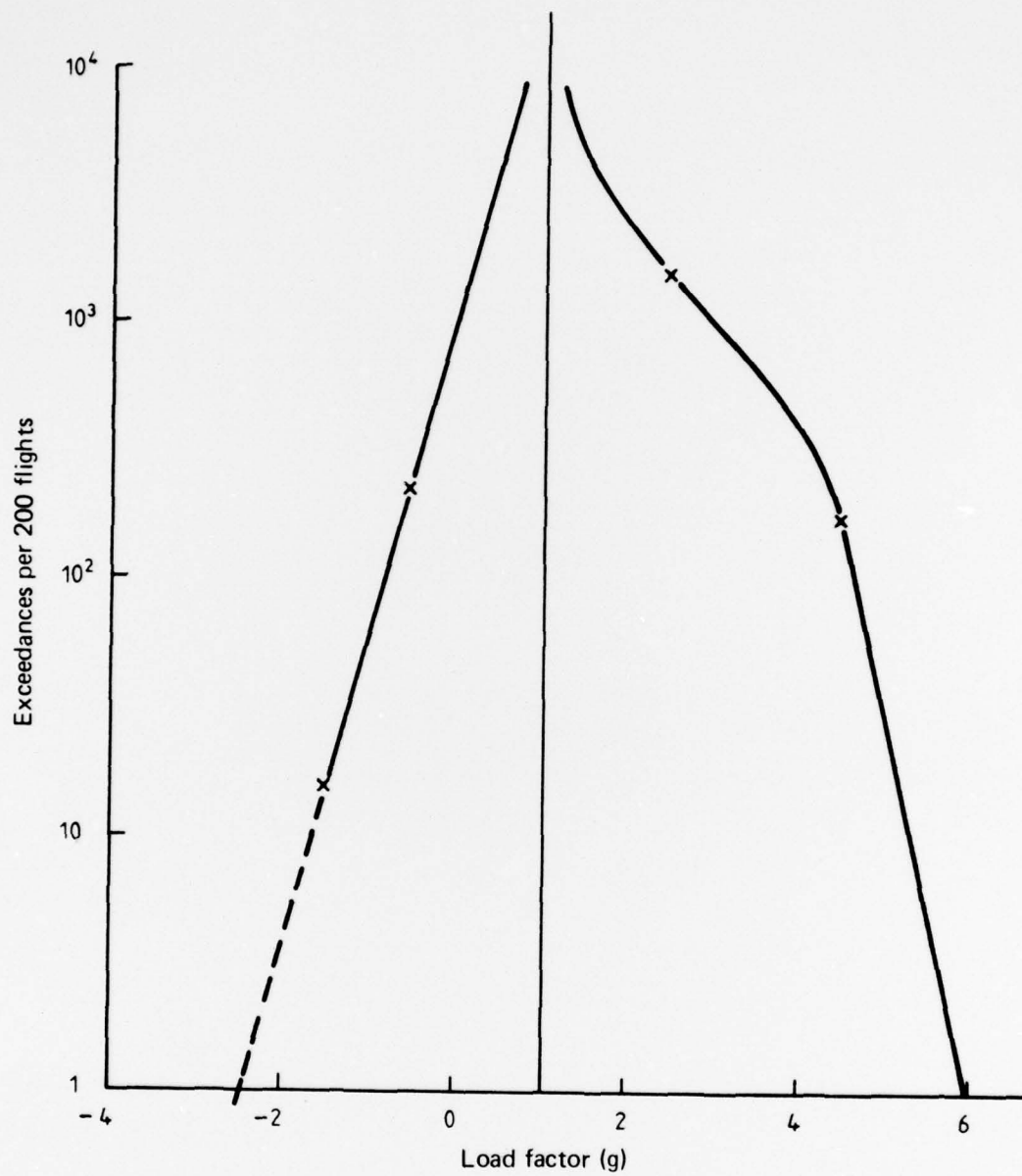


FIG. 3. LOAD SPECTRUM FOR BOTH PEARCE FATIGUE METER DATA AND ACTUAL FATIGUE TEST TAPE.

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TOF	Exceedance Levels (g)						Number of Missions
	-1.5	-0.5	2.5	3.5	4.5	6.0	
0	215	3580	19983	12592	2942	13	1992
5	820	12827	79584	44054	8846	48	8863
10	18	358	2918	1125	195	1	1484
20	15	187	3317	1164	192	1	898
30	16	300	2219	1437	426	9	194
40	27	415	9770	5681	953	6	2180
70	119	714	3096	2320	583	4	128
							Total 15739

TOF	Exceedance Levels (g)						Number of Missions
	-1.5	-0.5	2.5	3.5	4.5	6.0	
0	3	45	251	158	37	0	25
5	11	164	1015	562	113	1	113
10	0	5	37	14	2	0	19
20	0	2	41	14	2	0	11
30	0	3	23	15	4	0	2
40	0	5	126	73	12	0	28
70	2	11	48	36	9	0	2
							Total 200

TABLE 3
Flights done during flight trials—1974

ARDU* Recorded flight No.	Date	Pilot	Location
1376	12-2-74	Dickens	Laverton
1377	12-2-74	Dickens	Laverton
1378	13-2-74	Dickens	Laverton
1379	14-2-74	Dickens	Laverton
1381	15-2-74	Dickens	Laverton
1382	27-2-74	Dickens	Laverton
1385	7-3-74	Doyle	Laverton
1386	8-3-74	Doyle	Laverton
1387	12-3-74	Ashbrook	Laverton

* Aircraft Research and Development Unit—R.A.A.F.

TABLE 4
Flight Transition Matrix

TOF	Following TOF						
	0	5	10	20	30	40	70
0	0	774	158	104	20	184	11
5	782	0	674	424	71	951	61
10	152	676	0	104	13	115	15
20	99	407	110	0	8	96	3
30	15	81	14	7	0	17	2
40	197	973	100	78	21	0	12
70	5	51	18	8	3	19	0

TABLE 5
Run Length Matrix

TOF	Run Length														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	813	283	90	28	17	12	3	3	1	2	0	0	0	0	0
5	1150	661	411	224	145	102	70	49	31	22	24	15	12	7	9
10	750	264	44	12	4	1	0	0	0	0	0	0	0	0	0
20	592	104	23	6	1	0	0	0	0	0	0	0	0	0	0
30	95	28	10	2	1	0	0	0	0	0	0	0	0	0	0
40	894	328	88	37	22	7	4	0	3	0	1	0	0	0	0
70	86	15	1	1	1	0	0	0	0	0	0	0	0	0	0

TABLE 5 (continued)

TOF	Run Length														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	6	5	1	6	3	4	1	2	3	0	1	1	1	1	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 6
Scaled and Corrected Flight Sequence Matrix

TOF	Following TOF						
	0	5	10	20	30	40	70
0	0	10	2	1	0	3	1
5	10	0	9	5	1	14	1
10	2	9	0	3	0	1	0
20	1	5	2	0	1	1	0
30	0	1	1	0	0	0	0
40	3	14	1	1	0	0	0
70	1	1	0	0	0	0	0

TABLE 7
Scaled Run Length Matrix

TOF	Run Length												
	1	2	3	4	5	6	7	8	9	10	11	12	13
0	12	3	1	1	0	0	0	0	0	0	0	0	0
5	16	8	7	2	2	1	2	0	1	0	0	0	1
10	11	4	0	0	0	0	0	0	0	0	0	0	0
20	9	1	0	0	0	0	0	0	0	0	0	0	0
30	2	0	0	0	0	0	0	0	0	0	0	0	0
40	13	4	1	1	0	0	0	0	0	0	0	0	0
70	2	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 8
Channels Selected from Flight Trials Data in the First Stage of Data Extraction

Selected Channels	Function	Scale Factor	Units
7	n_z	100	g
20	SG. 20	1	μ -strain
21	SG. 23	1	"
25	SG. 48	1	"
28	SG. 46	1	"
38	SG. 36	1	"
39	SG. 37	1	"
42	SG. 19	1	"
43	SG. 21	1	"
44	SG. 22	1	"
45	SG. 24	1	"
46	SG. 32	1	"
47	SG. 33	1	"
48	SG. 34	1	"
49	SG. 35	1	"

TABLE 9
FM Spectrum for Flight Trials and Quasi-Flights
 Macchi RF 1376 12-2-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	1	1	2	2
-0.5	2	2	3	4	5	6	6
2.5	12	14	15	15	15	16	16
3.5	6	8	9	10	13	13	13
4.5	0	1	2	5	8	8	9
6.0	0	0	0	0	0	1	2
8.0	0	0	0	0	0	0	0

Macchi RF 1377 13-2-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	1	3	3	3
-0.5	3	4	4	5	5	5	5
2.5	9	9	10	14	16	17	17
3.5	7	9	11	11	11	11	11
4.5	0	1	3	6	8	9	11
6.0	0	0	0	0	0	1	3
8.0	0	0	0	0	0	0	0

Macchi RF 1378 13-2-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	0	0	0	0
-0.5	0	0	0	0	0	0	0
2.5	0	0	0	0	0	1	1
3.5	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0
6.0	0	0	0	0	0	0	0
8.0	0	0	0	0	0	0	0

TABLE 9 (continued)
Macchi RF 1379 14-2-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	0	0	0	0
-0.5	0	0	0	0	2	3	4
2.5	13	13	13	14	14	14	14
3.5	4	8	10	12	15	15	15
4.5	0	0	3	3	6	9	10
6.0	0	0	0	0	0	0	3
8.0	0	0	0	0	0	0	0

Macchi RF 1381 (26) 15-2-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	0	1	1	1
-0.5	1	1	1	1	1	1	1
2.5	6	6	8	9	10	11	11
3.5	2	7	10	13	12	15	13
4.5	0	0	1	2	4	8	10
6.0	0	0	0	0	0	0	0
8.0	0	0	0	0	0	0	0

Macchi RF 1382 (27) 27-2-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	0	0	1	1
-0.5	1	1	1	1	1	1	1
2.5	2	2	2	3	3	3	3
3.5	0	0	0	0	2	2	3
4.5	0	0	0	0	0	0	0
6.0	0	0	0	0	0	0	0
8.0	0	0	0	0	0	0	0

TABLE 9 (continued)
Macchi RF 1385 (030) 7-3-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	0	0	0	0
-0.5	0	1	1	1	2	2	4
2.5	9	14	14	14	15	15	16
3.5	6	7	12	12	13	14	16
4.5	0	3	6	6	6	10	12
6.0	0	0	0	0	1	3	5
8.0	0	0	0	0	0	0	0

Macchi RF 1386 (31) 8-3-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	0	0	0	0
-0.5	0	0	0	0	0	0	0
2.5	1	1	1	2	4	4	4
3.5	0	0	0	0	1	1	1
4.5	0	0	0	0	0	0	0
6.0	0	0	0	0	0	0	0
8.0	0	0	0	0	0	0	0

Macchi RF 1387 (32) 12-3-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	0	0	0	0
-0.5	0	0	2	3	3	3	3
2.5	12	12	12	12	14	14	14
3.5	6	7	10	12	15	15	15
4.5	2	3	4	6	6	7	10
6.0	0	0	1	2	3	3	4
8.0	0	0	0	0	0	0	1

Table 9 (continued)
Macchi RF 138B (26) 15-2-74

n_z	Exceedances for Each K Factor						
	0.8	0.9	1.0	1.1	1.2	1.3	1.4
-2.5	0	0	0	0	0	0	0
-1.5	0	0	0	0	1	1	1
-0.5	1	1	1	1	1	1	1
2.5	11	11	19	19	19	19	19
3.5	2	6	9	14	13	16	14
4.5	0	0	1	2	4	6	9
6.0	0	0	0	0	0	0	0
8.0	0	0	0	0	0	0	0

TABLE 10
Flight Trials Flights Corresponding to
Pearce Flights

Type	TOF (Pearce)	Flight Trials Histories
1	0, 5, 30, 70	1376 1377 1379 1382 1385 1386 1387
2	10, 20, 40	1378 138B

TABLE 11
FM Spectrum for the Two Types of Flying Done at Pearce

Type	Exceedance Levels (g)						No. of flights
	-1.5	-0.5	2.5	3.5	4.5	6.0	
1	16	223	1337	771	163	1	142
2	0	12	204	101	16	0	58
Total	16	235	1541	872	179	1	200

TABLE 12
Results of Linear Program

Type 1								
No. of Flights	Flight Code	K (Ref. 3)	Exceedance Levels (g)					
			-1.5	-0.5	2.5	3.5	4.5	6.0
49	1376	0.9	0	98	686	392	49	0
7	1376	1.0	0	21	105	63	14	0
16	1376	1.1	16	64	240	160	80	0
13	1377	0.8	0	39	117	91	0	0
6	1379	1.0	0	0	78	60	18	0
50	1386	1.1	0	0	100	0	0	0
1	1387	0.9	0	0	12	7	3	0
Total 142	—	—	16	222	1338	773	164	0
Type 2								
46	1378	0.8	0	0	0	0	0	0
2	138B	0.8	0	2	22	4	0	0
1	138B	0.9	0	1	11	6	0	0
7	138B	1.0	0	7	133	63	7	0
2	138B	1.2	2	2	38	26	8	0
Total 58	—	—	2	12	204	99	15	0
Grand Total 200	—	—	18	234	1542	872	179	0

TABLE 13
FM Spectra from Pearce Data and 200 Flight Test Tape

	Exceedance Levels (g)					
	-1.5	-0.5	2.5	3.5	4.5	6.0
Pearce	16	235	1541	872	179	1
Test tape	16	235	1541	872	179	1

Flight Sequence Example

Starting at the bottom left hand corner of Table A1, compare row and column totals (1 and 16) with the required totals from the run length Table A2 (2 and 17). The addition of 1 at 0/70 produces agreement in both directions. Therefore go to the bottom of the next column (5) and move upwards checking the row totals. At 40/5 the addition of 2 satisfies the two totals. In the third column, however, the addition of 1 at 20/10 satisfies column 10 but still leaves a deficiency in row 20. Since the following flight sequences must differ, the leading diagonal is fixed at zero. Hence row 20 must wait for the addition of 1 at 20/30. The process continues to the upper right element 0/70, with all totals now satisfied.

TABLE A1
Scaled Flight Sequence Matrix

TOF	Following TOF							Total
	0	5	10	20	30	40	70	
0	0	10	2	1	0	2	0	15
5	10	0	9	5	1	12	1	38
10	2	9	0	2	0	1	0	13
20	1	5	1	0	0	1	0	8
30	0	1	1	0	0	0	0	2
40	3	12	1	1	0	0	0	17
70	0	1	0	0	0	0	0	1
Total	16	38	14	8	1	16	1	

TABLE A2
Scaled Run Length Matrix

[illegible]

APPENDIX 2

Matching of Spectra

Suppose we have a type of flying (e.g. TOF1) with a spectrum as shown.

$$\begin{array}{c} \text{Exceedance Levels (g)} \\ -1.5 \quad -0.5 \quad 2.0 \quad 3.0 \\ \mathbf{k} = [1 \quad 2 \quad 4 \quad 2] \end{array}$$

Then if $N = 100$ flights of TOF1 the spectrum will be:

$$N\mathbf{k} = [100 \quad 200 \quad 400 \quad 200]$$

Given 5 flight trials histories, each having a spectrum shown below:

$$\begin{array}{c} \text{Exceedance Levels (g)} \\ -1.5 \quad -0.5 \quad 2.0 \quad 3.0 \\ \begin{array}{l} \text{A} \\ \text{B} \\ \text{C} \\ \text{D} \\ \text{E} \end{array} \begin{bmatrix} 2 & 1 & 2 & 1 \\ 3 & 5 & 10 & 7 \\ 0 & 1 & 4 & 2 \\ 0 & 3 & 4 & 2 \\ 5 & 10 & 10 & 5 \end{bmatrix} = k_{ft}, \text{ say,} \end{array}$$

how many of each of the above 5 flights will produce the same spectrum as $N\mathbf{k}$?

Let $X_A =$ No. of flights of type A etc.

with $\mathbf{x} = [X_A, X_B, X_C, X_D, X_E]$.

To maintain the counts at each level we get:

$$\begin{bmatrix} 2 & 3 & 0 & 0 & 5 \\ 1 & 5 & 1 & 3 & 10 \\ 2 & 10 & 4 & 4 & 10 \\ 1 & 7 & 2 & 2 & 5 \end{bmatrix} \begin{bmatrix} X_A \\ X_B \\ X_C \\ X_D \\ X_E \end{bmatrix} = \begin{bmatrix} 100 \\ 200 \\ 400 \\ 200 \end{bmatrix}$$

or briefly

$$k_{ft}' \mathbf{x} = N\mathbf{k}'$$

Also we require a total of $N = 100$ flights

$$\text{so} \quad X_A + X_B + X_C + X_D + X_E = 100$$

We have 5 unknowns and 5 equations, so our first choice would normally be to use any standard method for solving simultaneous equations. However, we have a constraint, namely that no value of X may be negative. For a best solution of the equations, given the constraint, we use linear programming.

This gives the rounded results:

$$\mathbf{x} = [35 \quad 10 \quad 32 \quad 23 \quad 0],$$

with a total of 100 flights and a spectrum $k_{ft}' \mathbf{x}$ with contributions:

Exceedance Levels (g)				No. of Flights
-1.5	-0.5	2.0	3.0	
$[\text{diag } \mathbf{x}] \mathbf{k}_{ft} = \begin{bmatrix} 70 & 35 & 70 & 35 \\ 30 & 50 & 100 & 70 \\ 0 & 32 & 128 & 64 \\ 0 & 69 & 92 & 46 \end{bmatrix}$				$\begin{bmatrix} 35 \\ 10 \\ 32 \\ 23 \end{bmatrix} = \mathbf{x}$
Totals $N\mathbf{k}_0 = \mathbf{k}_{ft}^t \mathbf{x} = [100 \quad 186 \quad 390 \quad 215]$				100

This is the optimum solution. The discrepancies present can be corrected by altering some of the n_z values in the actual flight histories.

In the example, \mathbf{x} is the solution of the more general linear programming problem we now describe. The spectrum achieved for a given trials matrix is:

$$\mathbf{k}_{ft}^t \mathbf{x} = N\mathbf{k}_0, \text{ say, } X_A + X_B + \dots + X_E = N$$

To best fit the required spectrum \mathbf{k} for the given TOF, the objective function to minimize is:

$$J = N\mathbf{a}^t |\mathbf{k} - \mathbf{k}_0| = N\mathbf{a}^t |\mathbf{k}_{ft}^t \mathbf{x} - \mathbf{k}|$$

Where \mathbf{a} is some weight vector and moduli are interpreted termwise.

The constraints of course are:

$$\mathbf{x} \geq 0$$

$$\text{and } X_A + \dots + X_E = N$$

In the example $\mathbf{a} = [1 \quad 1 \quad 1 \quad 1 \quad 1]$.

APPENDIX 3
List of Programs

Computer programs used for this project can be located on DECTape 358 and accessed using
DPIP

Program	Function
FATMET.F4	Produces the sequence and run tables for the raw FM data. Subroutines called: SEQ Output name: PJHFM.OUT
DATRUN	Scales and modifies sequence and run tables. Subroutines called: ROUNOF, FUDGE Output name: MODAT
FTSEQ.F4	Produces sequence of 200 flights, requires program RERUN.EXE on disk. Output name: FLIGHT.SEQ
MACEXT.F4	Produces 50 channel edited data from flight trials data. Output: To magnetic tape.
TURNPT.F4	Extracts turning points of N_z from edited flight trials tapes. Output name: TURNPT.OUT
FMSPEC.F4	Does a fatigue meter type count and simulates quasi flights from TURNPT.OUT Output name: typed in manually.
SIMPL	Matches corrected combinations of flight trials FM counts to Pearce FM data. Uses simplex method of linear programming. Output: to teletype.
MATAPE.F4	Produces new flight sequence using results of SIMPL with original flight sequence. Output name: FLTSEQ.NEW
MASEQ.F4	Fits load histories to each of the 200 flights in the sequence. Output name: F001 to F200
TAPWRT	Transfers 200 files in order from disk to magnetic tape.
FMKNT.F4	Does a fatigue meter type count on the 200 flight histories. Output name: FM.OUT

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16. ABSTRACT

This Note describes the development of a flight Load sequence for the fatigue testing of Macchi MB 326H spar booms. The procedure involves the use of linear programming and may be applied to other structures.

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